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DOD/NASA System Impact Analysis (Study 2.1) Final Report Volume I Executive Summary

Prepared by
ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

15 September 1973

Prepared for **OFFICE OF MANNED SPACE FLIGHT**
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2472

Systems Engineering Operations

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Volume I: Executive Summary

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FOREWORD

Study 2.1, "DOD/NASA System Impact Analysis," was managed by the Advanced Missions Office of the NASA Office of Manned Space Flight. Mr. Marion Kitchens was the NASA Technical Director of this study. Mr. A. R. Maffei was the Aerospace Corporation Study Manager and was assisted by Mr. D. L. Mumper. Technical support was provided by Messrs. T. J. Lang, B. Moffat, and F. S. Howard.

CONTENTS

FOREWORD	iii
1. INTRODUCTION.	1
2. STUDY OBJECTIVES	2
3. TUG TURNAROUND COST STUDY	3
A. Method of Approach and Principal Assumptions	3
1. Study Approach	3
2. Ground Rules/Guidelines	4
B. Basic Data Generated and Significant Results	4
1. Background	4
2. Scope	5
3. Results	5
4. STS ABORT MODES AND EFFECTS STUDY	12
A. Method of Approach and Principal Assumptions	12
B. Basic Data Generated and Significant Results	13
1. Abort Impacts	13
2. Tug Abort Performance Capability	15
3. Tug Autonomous Abort Assessment	16
5. SUGGESTED ADDITIONAL EFFORT	19
A. Tug Turnaround Costs	19
1. Indirect Operations Costs	19
2. Tug Refurbishment Logistics Concepts	20
B. STS Abort Modes and Effects	20
APPENDIX A	22

TABLES

3.1	Tug Direct Operating Costs, Bottoms-Up Estimate	8
3.2	Tug Indirect Operating Costs, Bottoms-Up Estimate	9
3.3	Tug Institutional Base Costs (\$Millions per year).	10
3.4	Tug Turnaround Cost Estimate Summary, 304 Tug Flights - 12-Year Program	11
4.1	STS Abort Effects/Impacts Summary	14
4.2	Space Tug Degraded Mission and Abort Performance Summary	17

1. INTRODUCTION

This final report contains the results of the FY 1973 NASA Study 2.1 performed under contract NASW-2472. This study, entitled "DOD/NASA System Impact Analysis," as originally proposed and negotiated at a level of approximately two man-years, was to consist of ad hoc system analyses as required, a Tug Turnaround Cost Study, and a Tug Refurbishment Logistics Concepts Study. No ad hoc studies were initially specified. In October 1972, direction was given by NASA to conclude the Tug Turnaround Cost Study and to initiate a Space Transportation System (STS) Abort Modes and Effects Study. In January 1973, additional direction was given to update a Space Shuttle Explosive Equivalency Study which had been accomplished under contract NASW-2129 in FY 1971. The Space Shuttle Explosive Equivalency Study was considered an ad hoc study but was covered by additional funding from the NASA Space Shuttle Program Office. The STS Abort Modes and Effects Study was retained as a replacement for the terminated Tug Turnaround Cost Study. The Tug Refurbishment Logistics Concepts Study was never initiated because the manpower allocated to Study 2.1 was expended, with NASA concurrence, in expediting the completion (to 29 November 1972 from March 1973) of the Tug Turnaround Cost Study and in performing the STS Abort Modes and Effects Study. Results of the Tug Turnaround and STS Abort Studies are contained herein while the results of the Explosive Equivalency Study are reported separately.

2. STUDY OBJECTIVES

The overall objective of this study, "DOD/NASA System Impact Analysis," was to conduct selected engineering and cost analyses regarding the elements of the Space Transportation System (STS). Specifically, as noted in the Introduction, a Tug Turnaround Cost Study and an STS Abort Modes and Effects Study were conducted. The objective of the Tug Turnaround Cost Study was to extend the results of a Tug Refurbishment Cost Study completed in FY 1972 to include all other costs related to turnaround. The objective of the STS Abort Modes and Effects Study was to identify the effects and impacts of abort on the flight and ground elements of the STS, viz., the Orbiter, Tug, Payloads, Ground Support, and Flight Support including Facilities and Equipments.

3. TUG TURNAROUND COST STUDY

A. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

1. STUDY APPROACH

As previously noted, the major objective of the study was to develop a Tug turnaround cost estimate; however, it was also necessary to retain the perspective of the Tug turnaround costs within the context of overall Tug operations costs. As a result, each of the following cost elements was addressed.

- a. Launch Operations
- b. Recovery Operations
- c. Command and Control
- d. Replacement Training
- e. Facility and Equipment Maintenance
- f. Vehicle Maintenance
- g. Engineering Support
- h. Program Integration and Management
- i. Follow-On Spares
- j. Propellants and Gases
- k. Range/Base Support.

These elements constitute the total Tug operations costs and are identical in definition and content to the cost estimating relationships (CERs) developed in a joint NASA/DOD-funded Space Transportation System (STS) Cost Methodology Study.¹ It was not the objective of this study to update or in any way modify the CERs; their definition and content were retained only for consistency and traceability.

¹STS Cost Methodology, Volume II, Orbit-to-Orbit Shuttle,
TOR-0059(6759-04)-1, The Aerospace Corporation (August 1970).

A significant portion of the turnaround and pre-flight costs for a reusable Tug is the refurbishment cost. This was the subject of an in-depth study conducted for NASA Headquarters in FY 1972. Since this Tug Turnaround Cost Study was an extension of the Tug Refurbishment Study, the results of the refurbishment study were used directly as cost inputs in the areas of vehicle maintenance and follow-on spares.

2. GROUND RULES/GUIDELINES

The following is a listing of the overall ground rules/guidelines used in the conduct of this study.

- a. The baseline Tug is that which resulted from the FY 1972 Tug Refurbishment Cost Study.
- b. The combined NASA/DOD mission model contains 304 Tug flights over a 12-year period with an approximate launch rate of two per month from KSC and one every two months from VAFB.
- c. The definition for each cost element analyzed is as stated in the STS Cost Methodology Study.
- d. NASA is assumed to be the host at KSC and DOD is assumed to be the host at VAFB.
- e. Tug maintenance facilities will exist at KSC and VAFB.
- f. Normal and contingency operations are considered in Tug turnaround operations.
- g. Separate estimates for IOC (first 20 flights) and full operational capability (OC) are presented where appropriate.
- h. Cost estimates are in 1971 dollars (multiply by 1.07 to obtain 1973 dollars).

B. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

1. BACKGROUND

During FY 1972 a Tug Refurbishment Cost Estimate was developed for a reusable cryogenic propellant Tug. This effort, conducted as part of Study 2.4 of contract NASW-2301¹, consisted of an in-depth analysis of the scheduled and unscheduled refurbishment costs of a representative Space Tug.

¹ Analysis of Space Tug Operating Techniques - Final Report (Study 2.4), Vol. II, ATR-73(7314)-1, The Aerospace Corporation (August 1972).

The Tug Turnaround Cost Study reported herein is the extension of the Tug Refurbishment Study to include other direct and indirect ground operations costs that are incurred in the turnaround cycle. Additionally, all other remaining operations cost elements are assessed to present a complete picture of the total expected operations costs of the Space Tug.

2. SCOPE

The Tug Turnaround Cost Study was intended to be a bottoms-up cost estimate of all Tug operational cost elements, with results available approximately six months after contract NASW-2472 go-ahead. This study was accelerated to completion in two and one-half months because of the higher priority of the Abort Modes and Effects Study. As a result, the study was terminated at this interim milestone producing operations costs which were derived by a mixture of bottoms-up and historically-based parametric costs, i. e., cost estimating relationships (CERs).

3. RESULTS

During the FY 1972 Tug Refurbishment Cost Study of contract NASW-2301, it was recognized that maintenance and refurbishment represented only a portion of the total ground turnaround costs. The results noted herein utilized the FY 1972 Tug maintenance and refurbishment costs augmented by an analysis of the additional direct and indirect operational costs required to support the ground turnaround cycle of a Tug. In the conduct of the study and in keeping with the Statement of Work all operational cost elements were assessed for the purpose of understanding Tug turnaround costs within the context of overall Tug operations costs.

To realistically assess the operational costs as a function of the maturity of the system two time frames of reference were defined: an Initial Operational Capability (IOC) consisting of approximately 20 flights, and a full Operational Capability (OC) following IOC for the remainder of the 12-year mission model. These definitions were utilized in the predecessor

Tug Refurbishment Cost Study and were therefore carried into this study. Another carryover of significance was the use of a "dedicated" Tug ground crew at each launch site of 52 men for IOC and 37 men for OC. These crew sizes were determined in the Refurbishment Study by analyzing the necessary operations and skill mix required for maintenance and refurbishment. A review of the crew mix for this study revealed that the previously determined crews were sufficient to perform all ground operations. As a result, the "dedicated" Tug crew concept was also adopted for this study as opposed to a manpower pool. It is recognized that a cost savings might result if the Shuttle and Tug ground crews were combined into a manpower pool. It is recommended that this be considered in any follow-on study.

The major findings of this study are presented in Tables 3-1 (Direct Operating Costs), 3-2 (Indirect Operating Costs), 3-3 (Institutional Base Costs), and 3-4 (Cost Estimate Summary). As the definition of Tug turnaround cost can vary, i. e., with or without indirect costs, launch costs, etc., the following overall conclusions are presented which combine the Tug turnaround related operations costs in various ways.

- a. The total direct costs of an average¹ Tug turnaround, i. e., landing-to-launch, are \$519K and \$342K for the IOC and OC phases of the flight program, respectively.
- b. The total direct operational costs for Tug missions, i. e., launch-to-launch including flight operations, are \$665K and \$386K for IOC and OC, respectively.
- c. The total direct and indirect operational costs for Tug missions, i. e., launch-to-launch including flight operations, are \$1,020K and \$687K for IOC and OC, respectively.

¹ The average turnaround costs reported herein combine KSC and WTR operational costs and launch rates.

- d. A dedicated Tug ground crew at KSC of 37 men of appropriate skills is sufficient to perform all Tug-related ground operations for the maximum expected launch rate of two per month (OC).
- e. The necessity for a similar 37-man crew at WTR combined with its significantly lower Tug launch rate of one every two months (6 per year) could result in significantly higher actual costs per flight at WTR.
- f. Government (NASA, DOD, etc.) and non-government user costs may differ significantly due to government policy on the apportionment of many indirect costs to the non-government user. It is recommended that this be pursued in any subsequent effort.

Table 3-1. Tug Direct Operating Costs, Bottoms-Up Estimate

	Manpower Pool		Dedicated Tug Crew	
	IOC	OC	IOC	OC
Ground Operations				
Launch	384 m hr/flt ¹	256 m hr/flt	} 104 myr/yr ²	74 myr/yr
Recovery	156 m hr/flt	104 m hr/flt		
Vehicle Maintenance	3,546 m hr/flt	2,482 m hr/flt		
Spares	\$368 K/flt	\$231 K/flt	\$368 K/flt	\$231 K/flt
Propellants	\$11 K/flt	\$11 K/flt	\$11 K/flt	\$11 K/flt
Flight Operations				
Command and Control	80 myr/yr	24 myr/yr	80 myr/yr	24 myr/yr

¹Man hours per flight.

²Man years per year, 2 sites.

Table 3-2. Tug Indirect Operating Costs, Bottoms-Up Estimate

	IOC	OC
Facility & Equipment Maintenance	\$3,112 K/yr	\$3,112 K/yr
Replacement Training (\$17 K/man)	26 men/yr	18.5 men/yr
Engineering Support (\$46 K/myr)	93 myr/yr	71 myr/yr
Program Integration & Management (\$46 K/myr)	25 myr/yr	20 myr/yr

Table 3-3. Tug Institutional Base Costs (\$Millions per year)

	CURRENT BUDGET	STS ESTIMATE	TUG ESTIMATE
Range and Base Support			
AFETR	\$134 M	\$100 M	} \$48.3 M
KSC	\$ 71 M	\$ 60 M	
AFWTR (SAMTEC)	\$ 76 M	\$ 19 M	} \$ 5.7 M
VAFB	\$ 20 M	\$ 20 M	
Mission Support			
AFSCF (Including RTS)	\$150 M	\$ 25 M	\$ 8.3 M
MCC (Including STDN and MSFN)	ASSUMED EQUAL TO AFSCF ESTIMATE		

Table 3-4. Tug Turnaround Cost Estimate Summary,
304 Tug Flights - 12-Year Program

Direct - 10 ³ Dollars/Flight *	MANPOWER POOL		DEDICATED TUG CREW	
Ground Operations	IOC	OC	IOC	OC
Launch	7 *	4	} 140	100
Recovery	3	2		
Vehicle Maintenance	60	42		
Spares	368	231	368	231
Propellants	11	11	11	11
Flight Operations				
Command and Control	146	44	146	44
Indirect - 10 ³ Dollars/Yr **	IOC		OC	
Facility & Equip. Maint.	3,112 **		3,112	
Replacement Training	449		319	
Engineering Support	4,278		3,266	
Program Int. & Mgt.	1,150		920	
Institutional - 10 ³ Dollars/Yr **				
Range & Base Support	54,000 **			
Mission Support	16,600			

4. STS ABORT MODES AND EFFECTS STUDY

A. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The overall objective of this study was to assess the major effects and impacts of abort on the flight and ground elements of the STS, viz., the Orbiter, Tug, Payload, Ground Support, and Flight Support including Facilities and Equipments. The main emphasis of this study was on the identification of Tug-related abort effects and impacts, i. e., those that are caused by the Tug and those that affect the Tug. The performance capability of the Tug vehicle with either degraded main engine thrust or reaction control system thrust was analyzed as a special emphasis task. Also, a cursory analysis was made to assess the data management system requirements for performing all Tug-related abort decisions and operations on board the Tug vehicle.

The approach used in this assessment was to first define the baseline STS elements and a baseline mission. Shuttle vehicle definition was obtained from information presented by North American Rockwell in their November 1972 Space Shuttle System Summary and Program Requirements Review Briefings. The Tug vehicle definition was obtained from the NASA MSFC June 26, 1972, "Baseline Tug Definition Document." Since the payloads to be put into orbit by the STS are many and diverse, representative systems/subsystems were considered; however, no particular baseline design was assumed. The mission used for this assessment was a geosynchronous 1361 kg (3000 lb) payload replacement mission.

Abort regimes were then defined for all phases of the baseline mission from liftoff to reentry. The next step was to determine the gross effects on the STS elements of an assumed abort producing failure in each flight element for each abort regime. This step provided an overview of the abort problem and ensured that all general categories of abort were addressed. The next step in the assessment was to define the actual failure or failure

modes and then relate these to impacts on the STS elements. Because of the state of the design of the Orbiter and Tug vehicles and the many diversified payloads that are planned to be orbited by the STS, a detailed analysis of all the possible failure modes of these STS elements was not attempted. Therefore, the failure analysis was limited to a gross assessment of the possible failure modes and hazards and was made with the following limitations and assumptions: (1) the cause of failure was generally not isolated beyond the subsystem level, (2) no numerical probabilities were calculated, and (3) only payload types that require a Tug mission for payload replacement were considered.

For the special emphasis task to determine Tug performance with degraded thrust levels, a six degree of freedom flight simulation computer program was utilized. Both intact (with payload) and jettisoned payload aborts were analyzed. For the autonomous abort assessment, functional requirements for Tug autonomous abort capability were defined and their impact on the design of the Tug on-board data management system was assessed. Rough estimates of software and hardware requirements were made, together with a projection of flight computer capability in the 1976-80 time frame.

B. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

1. ABORT IMPACTS

The resultant major effects and impacts on the STS elements of an abort-producing failure in one of the flight elements are presented in Table 4-1. These are related to either the design of the elements or operational procedures. The main design impacts on the elements are summarized below.

- a. An abort during the Shuttle ascent phase of the mission impacts both the Orbiter and Tug design. These vehicles must be designed to land with a full load of Tug propellants or provide for rapid dumping.
- b. A failure in the baseline Tug electrical power supply (single fuel cell) could result in the loss of the Tug and its payload.

Table 4-1. STS Abort Effects/Impacts Summary

STS ELEMENT	FAILURE MODE	GROSS EFFECT ON ELEMENT	ELEMENT IMPACT
ORBITER	1. Shuttle propulsion system or solid rocket motor failure during ascent phase.	1. Land with fully or partially fueled Tug.	1. Design for additional payload weight during return/reentry, accept lower safety factors during reentry, or provide for rapid Tug propellant dump.
	2. Damage to Orbiter/Tug docking mechanism.	2. Inability to properly secure Tug inside bay for reentry may be catastrophic.	2. Develop operational procedures to adequately determine the status of the Orbiter/Tug latching mechanism.
TUG	1. Shuttle propulsion system or solid rocket motor failure during ascent phase.	1. Land with full or partially full propellant tanks.	1. Design for structural integrity to land with full propellant tanks or provide for rapid propellant dump.
	2. Tug or payload failure which necessitates Tug return to Orbiter.	2. Determine proper phasing for unscheduled return to Orbiter parking orbit.	2. Tug must be able to do on-board mission planning or have communication with ground control.
	3. Orbiter return to earth without Tug due to Orbiter failure.	3. Remain in low earth parking orbit for extended time for retrieval by subsequent Orbiter flight.	3. Tug would have to survive extended on-orbit stay time. Baseline design limited in respect to on-orbit stay capability.
	4. Tug electrical power failure.	4. Loss of Tug vehicle.	4. Baseline design has single fuel cell. Add a redundant fuel cell to reduce this risk.
	5. Tug electrical power failure just prior to retrieval by Orbiter (due to H ₂ leak).	5. Creates possible hazard inside Orbiter bay due to possible H ₂ leak, if Tug is retrieved.	5. Operational procedure needed to determine fuel cell status prior to retrieval.
	6. Failure in Tug main propulsion system.	6. Perform mission or abort without main engine thrust.	6. Tug could return to Orbiter using the auxiliary propulsion system (APS) if the APS had access to the main engine propellants. Baseline design does not have this feature.
	7. Failure of Tug propellant tank insulation system.	7. Excessive propellant boil-off.	7. Excessive propellant boil-off would require that the Tug return immediately to the Orbiter for retrieval.
PAYLOAD	1. Tug failure which necessitates jettisoning the payload and returning to Orbiter.	1. Deployed in off-nominal orbit.	1. Payload would remain in off-nominal orbit until retrieval by a subsequent Tug flight.
GROUND	1. Shuttle failure during ascent phase which requires immediate return to launch site.	1. Tug returned with full or partially full propellant tanks.	1. Ground servicing equipment and operations must provide for horizontal Tug propellant drain.
	2. Failure in STS flight elements which requires early return of elements.	2. Altered flow of flight elements through ground turnaround cycle.	2. The early return of the flight elements may tax the capabilities of the ground facilities.
	3. Failure in any of the flight elements which necessitates an abort action.	3. Communication with the flight elements may be necessary to assist in abort procedures.	3. The ground may be required to provide executive confirmation and real time mission planning in abort situations.

- c. Orbiter aborts after Tug deployment could result in the requirement to extend the quiescent on-orbit Tug capability.
- d. A Tug failure could result in payload abandonment in an off-nominal orbit.
- e. Altered flow of flight elements through the ground turnaround cycle due to a mission abort may tax the capabilities of the ground facilities.
- f. Partial mission completion may be possible in the event of a Tug main engine failure by using either Tug main engine idle mode or reaction control system thrust. The reaction control system requires access to the main propellants in order to provide the required ΔV . The baseline Tug design used for this assessment does not have this feature.

2. TUG ABORT PERFORMANCE CAPABILITY

During the conduct of the abort effects assessment, it was recognized that the Tug main propulsion system represented a significant single point failure mode. A special emphasis task was conducted therefore to analyze the mission performance capability of the Tug at degraded thrust levels.

The mission used for this analysis was the baseline geosynchronous payload replacement mission. The nominal Tug mission consists of the following six burns:

- a. The first burn injects the Tug into a transfer orbit with apogee at synchronous altitude.
- b. The second burn circularizes the orbit at synchronous altitude.
- c. After deploying the first payload, the Space Tug performs a third burn (actually a series of burns) to accomplish on-orbit phasing and retrieve a second payload.
- d. With the second payload attached, a fourth burn is performed to lower the Tug's perigee altitude.
- e. As the Tug approaches perigee, a fifth burn is executed to produce a phasing orbit.
- f. The sixth burn circularizes the Tug orbit.

Loss of the nominal Tug thrust level of 44,482 N (10,000 lb) was assumed to occur prior to any one of the six burns. Failure modes considered were:

- a. Only the main engine idle mode thrust of 4448 N (1000 lb) was available.
- b. Only the Reaction Control System (RCS) thrust of 534 N (120 lb) was available.

The capability of the Tug in a degraded thrust condition is summarized in Table 4-2. If an abort mission cannot be completed, the orbit in which fuel is exhausted in attempting to return to the Orbiter is given. Dash lines in place of an entry indicate that an alternative is meaningless.

As indicated in Table 4-2, portions of the mission can be performed in the event of a main engine failure provided there is idle mode or RCS thrust available. After the mission orbit has been obtained, the performance capabilities of the two alternate thrust modes are the same except that the idle mode thrust can bring the Tug and its payload back to a lower earth orbit in the case of an intact abort. If a failure occurs in the main engine prior to obtaining the mission orbit, a deploy-only mission can be completed using the idle mode thrust but not with the RCS thrust.

3. TUG AUTONOMOUS ABORT ASSESSMENT

The ground support necessary for the STS elements during an abort situation is dependent on the on-board capabilities of the flight elements. A preliminary assessment was made to determine the data management system requirements for incorporating an autonomous abort capability into the unmanned Tug vehicle.

The data storage requirements and computing power needed to control the Tug through its baseline mission can be estimated with some degree of confidence by a straightforward extension of some current flight programs. The problem of dealing with non-nominal conditions is less well defined. The number of ways in which a complex system can exhibit non-nominal performance is distressingly large, and the decision processes

Table 4-2. Space Tug Degraded Mission and Abort Performance Summary

Mission to be Attempted	Failure to Reduced Thrust is Assumed to Occur Prior to					
	Burn 1 Transfer Orbit Insertion (up)	Burn 2 Mission Orbit Insertion	Burn 3 Retrieve Payload	Burn 4 Transfer Orbit Insertion (down)	Burn 5 Phasing Orbit Insertion	Burn 6 Circularize
Idle Mode Thrust	Replacement	No	No	No	No	Yes
	Deploy-Only	Yes	Yes	Yes	--	--
	Intact Abort ¹	Yes	--	No	No	Yes
	Jettison Abort ²	Yes	Yes	315 x 2036 km (170 x 1100 nmi) 28.5 deg	315 x 1944 km (170 x 1050 nmi) 28.5 deg	Yes
RCS Thrusters	Replacement	No	No	No	No	Yes
	Deploy-Only	No	Yes	Yes	--	--
	Intact Abort ¹	Yes	--	No	No	Yes
	Jettison Abort ²	Yes	Yes	315 x 5183 km (170 x 2800 nmi) 27.5 deg	222 x 4445 km (120 x 2400 nmi) 27.7 deg	Yes

Yes - Mission can be completed.

No - Mission cannot be completed.

¹ Intact Abort - Return Tug and payload to Orbiter.

² Jettison Abort - Abandon payload in orbit and return Tug to Orbiter.

required to evaluate their impact on mission performance is correspondingly complex. An examination of existing ground programs which perform subsets of the complex system readiness, mission planning, and mission verification functions provides an estimate of the computer storage requirements for these functions. The results of the cursory assessment indicate that a computer size of 64K words would be adequate for all Tug functions including autonomous abort.

Other technical factors governing the design of the Tug on-board data management system include computing speed, size, weight, power consumption, and reliability. These factors must be considered in terms of the technology postulated to be available in the 1976-1980 time frame. These characteristics are summarized as follows:

Memory Capacity	64K 32-bit words (access time 0.3 μ sec)
Computing Speeds	Add time < 1 μ sec Mult Time < 5 μ sec
Volume	< 0.056 m ³ (2 ft ³)
Weight	< 22.5 kg (50 lb)
Power Consumption	~275 W

5. SUGGESTED ADDITIONAL EFFORT

A. TUG TURNAROUND COSTS

The Tug Turnaround Cost Study, being an extension of the previously completed Tug Refurbishment Cost Study, was limited to a single Tug configuration, i. e., high performance, cryogenic propellant, reusable Tug. It is recommended that the operational costs of the following Tug candidate concepts be studied to be compatible with alternate Tug concepts currently being analyzed by the NASA and DOD.

- a. Phased developed cryogenic propellant Tugs
- b. Storable propellant reusable Tug
- c. Modified existing upper stages.

As a result of this study several cost-driver areas were identified which warrant further in-depth study irrespective of the Tug concept selected. These areas are discussed in the subsequent paragraphs.

1. INDIRECT OPERATIONS COSTS

Indirect Tug Operations Costs include Facility and Equipment Maintenance, Replacement Training, Engineering Support, and Program Integration and Management. Of the operations costs, the cost-driver areas of Tug Equipment Maintenance and Engineering Support accounted for almost 40 percent of the total direct and indirect per flight operations costs. The recurring nature of the costs, which are somewhat independent of launch rate, necessitated an assumption of average launch rate to establish per flight costs. It is recommended that a comprehensive study be conducted regarding these indirect cost-driver areas and the applicability of these costs as user or institutional base costs.

2. TUG REFURBISHMENT LOGISTICS CONCEPTS

As noted in the Introduction, this study was originally planned to be accomplished within this contract following the accomplishment of the Tug Turnaround Cost Study. It was not accomplished due to the priority of other studies; however, it is recommended that it be considered in any subsequent effort. Major areas that should be addressed include the logistic relationships between NASA, DOD, and the various Tug contractors, i. e., vehicle, facilities, equipment, etc. Additionally, the effect of the Shuttle equipment and personnel at the same launch facilities should be addressed. Specifically, the study is needed to assess various approaches to Tug logistics. Various concepts concerning the approach to vehicle maintenance should be identified. The question of who will perform the maintenance and the impact on the total program should be addressed, e. g., private contractor versus the use of a government organization to perform vehicle maintenance. The impact on the funding level and the level of support required at the manufacturer for various approaches to spares support should be identified, i. e., all spares purchased at the beginning of the program or purchased over a longer time span.

B. STS ABORT MODES AND EFFECTS

The impacts on the various elements of an abort-producing failure in one of the STS flight elements represent design features and requirements that may or may not be practical or desirable to implement. The impact on the Orbiter of an abort during the ascent phase of the Shuttle flight is dependent on whether or not there is enough time to dump the Tug propellants. A trade study would be required to determine whether the Orbiter should provide for propellant dump, design for the added payload weight, or accept a reduction in the structure safety factors. The impacts on the Tug vehicle would also have to be considered. At the time of the writing of this report, the Shuttle abort capability was in the process of being revised, i. e., the capability for thrust terminating the solid rocket motors was deleted. This should result in an increase in the minimum time for propellant dump. Until the Shuttle abort capabilities are adequately defined, no definite design impacts can be determined.

In the event of an Orbiter failure which necessitates the early return of the Orbiter prior to Tug retrieval, the Tug may be required to remain on orbit longer than anticipated. If the failure occurred just prior to Tug retrieval and the Orbiter required two weeks to be refurbished and processed through the ground turnaround cycle, then the Tug would have to stay on orbit an additional two weeks if no other Orbiter were available. The baseline Tug has approximately seven days on-orbit capability. Hence, some of the Tug systems, e.g., electrical power and propellant supply for attitude control, would require additional capability to survive the added time on orbit. The degree to which this added capability should be incorporated and the resultant impact on the Tug design should be the subject of a study.

The main impact on the payload results from a Tug failure which requires the Tug to jettison the payload in an off-nominal orbit. Hence, the payload would have to survive in this orbit until retrieval by a subsequent Tug flight. The impact on the payload is a function of the difference between the design orbit and the off-nominal orbit, i.e., if the payload were designed to operate at synchronous altitude but instead the payload were deployed in a low earth orbit the difference in the heat input from the earth's albedo and the sun may result in damage to the payload. Whether or not the payload should be designed to account for the possibility of an off-nominal orbit insertion should be the subject of a trade study which would address the probability of this occurrence and the impact on the subsystems in various payloads.

The preliminary analysis of data management system requirements for Tug autonomous abort capability has permitted a general definition of the scope of the problem and the development of some broad guidelines for further steps in the systems analysis/development process. The greatest single uncertainty factor in determining the overall feasibility of incorporating an autonomous abort capability in the Tug data management system is the question as to the degree to which the functions now performed by human beings in the areas of fault diagnosis, mission plan generation, and mission plan verification should be automated. This question should be addressed in any follow-on effort.

APPENDIX A
STUDY 2.1
DOD/NASA SYSTEMS IMPACT ANALYSIS

STATEMENT OF WORK

The Statement of Work, extracted from Request for Proposal No. W10-12296-DHC-3, is repeated below for the convenience of the reader.

"2.1 DOD/NASA System Impact Analysis

The contractor shall analyze the relative effectiveness of advanced STS programs identified by NASA. The contractor shall include in his analyses consideration of as many separable technical issues as possible which are related to the impact of the NASA-identified alternative programs on potential DOD technical requirements. In addition, the contractor shall provide NASA with as broad a technical understanding as possible of potential DOD program requirements and options as they might affect NASA planning.

2.1.1 Systems Analysis

The contractor's system analysis effort shall include consideration of technical, economic and programmatic factors, development schedules, growth potential and sensitivity to program changes. Where potential benefits are suggested by the systems analysis, the contractor shall conduct conceptual design/analysis activities in sufficient depth to establish first-order verification of the hypothesized program benefit and to identify the resulting vehicle implications. The contractor shall continue his cognizance over NASA and DOD-sponsored space vehicle and operations studies related to the Space Transportation System (STS) and shall identify areas of technical or economic uncertainty which require the conduct of advanced program studies for resolution.

The contractor shall perform system analysis in areas typified by the task listing below:

2.1.1.1 Conduct vehicle sensitivity analysis which will identify potential performance and physical characteristics variations which might be encountered, and provide design decision optimization data for use in developing a balanced strategy between performance optimization and downstream program growth.

2.1.1.2 Identify those program areas which are most likely to require change, and the preventive or remedial program management actions which would reduce the impact of changes on program performance, schedules and costs.

2.1.1.3 Identify program control techniques which will provide maximum timely insight into program trends.

2.1.1.4 Conduct analysis of space subsystems refurbishment and repair techniques, and evaluation of the impact of these techniques on subsystems costs and procurement strategy.

2.1.1.5 Identify potential product improvement areas and provide an assessment of the potential program benefit occurring from candidate improvements.

2.1.1.6 Identify and evaluate potential new space Shuttle applications.

2.1.2 DOD Applications of a NASA Designed Tug/Transfer Stage

The contractor shall utilize his familiarity with Tug/Transfer Stage design options and with DOD mission applications to provide NASA with a continuing assessment of the capability of a NASA designed Tug/Transfer Stage to perform DOD missions. Based upon the assessment, the contractor shall identify and describe modifications required to ensure that the developed Tug will have maximum compatibility with DOD missions. Typical of the tasks to be performed in this study activity are:

- 2.1.2.1 The contractor shall maintain cognizance of NASA directed Tug design studies and recommend appropriate study tasks.
- 2.1.2.2 Conduct in-house studies to determine the impact of DOD-unique requirements on the specific NASA Tug/Transfer Stage design(s).
- 2.1.2.3 Develop Tug fleet buy strategies based on established estimated attrition rates, to be developed as a part of this task, and evaluate production strategies as a means to incorporate product improvement changes at minimum expense.
- 2.1.2.4 Develop Tug subsystem failure detection, contingency action concepts and operations techniques.
- 2.1.2.5 Identify and develop techniques for monitoring, and controlling the Tug while in close proximity to the Shuttle. This should include a description of the required Tug and cooperating Shuttle subsystems.
- 2.1.2.6 Conduct analyses of Tug subsystem refurbishment and repair concepts together with the costs. Evaluate the impact of these concepts on Tug subsystem procurement strategy during the Tug development and operational phases.
- 2.1.2.7 Evaluate DOD Tug operations concepts, such as the identification of the conceptual subsystems as they affect DOD mission operations, and identification of the DOD-preferred flight operations and support systems (including the mission control process).
- 2.1.2.8 Develop comprehensive cost estimates for Tug turnaround (launch-to-launch) concepts. These should include recovery and return, post-flight safing, refurbishment and repair, and pre-launch checkout and support activities. "

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